519

VOLUME 80 SEPARATE No. 519

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

OCTOBER, 1954

DESIGN RAINFALL: CENTRAL AND SOUTHERN FLORIDA PROJECT

by L. A. Farrer, A.M. ASCE

IRRIGATION AND DRAINAGE DIVISION

{Discussion open until February 1, 1955}

Copyright 1954 by the AMERICAN SOCIETY OF CIVIL ENGINEERS
Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

THIS PAPER

--represents an effort by the Society to deliver technical data direct from the author to the reader with the greatest possible speed. To this end, it has had none of the usual editing required in more formal publication procedures.

Readers are invited to submit discussion applying to current papers. For this paper the final date on which a discussion should reach the Manager of Technical Publications appears on the front cover.

Those who are planning papers or discussions for "Proceedings" will expedite Division and Committee action measurably by first studying "Publication Procedure for Technical Papers" (Proceedings – Separate No. 290). For free copies of this Separate—describing style, content, and format—address the Manager, Technical Publications, ASCE.

Reprints from this publication may be made on condition that the full title of paper, name of author, page reference (or paper number), and date of publication by the Society are given.

The Society is not responsible for any statement made or opinion expressed in its publications.

This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

DESIGN RAINFALL
CENTRAL AND SOUTH FLORIDA PROJECT

L. A. Farrer,[1] A. M. ASCE

SYNOPSIS

The economic and design analyses of many sections of the Central and Southern Florida Project will be based on frequency studies. This paper describes the study which was made in order to determine the probability of the future occurrence of rainfall of various amounts and durations in central and southern Florida.

The purpose of the Central and Southern Florida Project is to provide basic water-control facilities necessary to prevent flooding and maintain desirable water levels on a relatively flat area of about 15,000 square miles. Although the system of canals, levees, and storage areas comprising the project is interrelated, it will be necessary to design the project as hundreds of individual units as well as groups of large interrelated units. Some features of the project will be designed to give protection against the standard project flood, which is defined in broad terms as the flood that would result from the most severe storm or sequence of storms considered reasonably characteristic of the region in which the project is located. The "standard project flood" is a very rare event, but is substantially less severe than the "maximum probable flood." The generalized rainfall charts and procedures for developing the standard project storm are described in publications distributed by the Corps of Engineers and will not be discussed herein. Economic studies will influence the design of other items such as canals and structures since benefits are derived largely from preventing crop damages and floods do not normally endanger lives or cause catastrophes. During floods the movement of water is very slow, and for months the rain may remain ponded on the land where it falls. In order to develop the economic data needed to justify and design many features of the project, it will be necessary to determine the frequency and severity of flooding in many areas under both pre-project and post-project conditions. The preparation of accurate flood-frequency studies for individual drainage units from run-off records is impracticable as the drainage divides often vary with the depth of water on the ground and run-off records are not available for many areas. Therefore frequency studies must be based on available rainfall records.

1. Chf., Meteorology and Regulation Section, Planning and Reports Branch, Corps of Engrs., U. S. Dept. of the Army, Jacksonville, Fla.

Before describing the details of the frequency study, a general description of the climatology of the area is needed. The climate of the area is sub-tropical and the four seasons of the temperate zone are replaced by the two seasons characteristic of tropical regions—wet and dry. About 65 percent of the mean annual rainfall occurs during the wet period from June through October. During the summer, local thunderstorms occur almost daily and produce most of the rainfall. Such storms are a result of strong convective currents caused by heating the air over black muck soils. Hurricanes or tropical storms pass over the area occasionally. Those storms sometimes produce very heavy rain, but only a small percent of the mean annual rainfall is caused by hurricanes. An analysis of the maximum rainfall recorded during 96 tropical storms which have affected Florida in the last 50 years shows that 10 percent of the storms had 24-hour rainfall amounts exceeding 13 inches and the median storm had 8 inches. About half of those storms were of hurricane intensity. Average annual rainfall in the project area varies from 47 to 65 inches. The greatest annual rainfall recorded is 136 inches, of which 103 inches fell during the period June through November. The maximum 24-hour rainfall recorded in the project area is 21.9 inches at Canal Point. A bucket survey of the September 1950 hurricane in the Cedar Key area indicated that 34 inches of rain fell in a 24-hour period. That survey established an unofficial rainfall record for the state. Rainfall records were available for a few stations in the area for periods of over 50 years; however, in the center of the area where water-control problems are most critical, the majority of the stations have been established in the last 15 years.

In order to make maximum use of the rainfall data available, a generalized study has been made for the area and frequency curves have been developed for nearly all rainfall stations in central and southern Florida with more than 10 years of record. The methods used are those described by L. R. Beard in a paper titled "Statistical Analysis in Hydrology," Transactions American Society of Civil Engineers, Vol. 108, page 1110, 1943, and in an unpublished paper, "Statistical Methods in Hydrology" (dated July 1952) which was distributed by the Office of the Chief of Engineers to all field offices of the Corps of Engineers with Civil Works Engineer Bulletin 52-24. The method is based on the supposition that the logarithms of maximum annual rainfall or run-off values are usually normally distributed and the curve of best fit will be a straight line on log-probability paper. The slope of the straight line is then a function of the standard deviation of the logarithms. Coefficients of standard deviation for a straight line (skew of 0.0) are given in table 1 for selected frequencies. However, if an analysis of the observations indicates that the data are not normally distributed, the frequency curve should be skewed. If the indications of skew are conclusive, Beard suggests that the curve of best fit for most hydrologic data will be a Pearson Type III curve and the study should be based on factors developed by H. A. Foster, in paper titled "Theoretical Frequency Curves," Transactions American Society of Civil Engineers, Vol. 87, page 142,

1924. Coordinates for curves of best fit varying from a straight line to curves with a skew coefficient of +0.8 were taken from a table prepared by Beard and are given in table 1.

TABLE 1

Skew curve coordinates

Skew coefficient	Magnitude in standard deviations from mean for exceedence percentages of								
	1	5	10	30	50	70	90	95	99
0	2.33	1.64	1.28	0.52	0.00	-0.52	-1.28	-1.64	-2.33
+0.2	2.48	1.69	1.30	0.51	-0.03	-0.55	-1.25	-1.58	-2.18
+0.4	2.62	1.74	1.32	0.48	-0.06	-0.57	-1.22	-1.51	-2.03
+0.6	2.77	1.79	1.33	0.45	-0.09	-0.58	-1.19	-1.45	-1.88
+0.8	2.90	1.83	1.34	0.42	-0.13	-0.60	-1.16	-1.38	-1.74

Records of storms varying in duration from one day to more than a month are required to determine critical flooding in the various parts of the project area. As the topography is very flat and initial losses and infiltration rates are high, the distribution of rainfall within a 24-hour period is not of major importance. Maximum daily rainfall frequencies were computed for 120 stations in Florida, while 2- 10-, and 30-day frequencies were developed for 13 key stations in the project area. The annual maximum rainfall values for the selected durations used in the study were taken from climatological records and tabulated. In some cases where a station has moved during the period of record, the observations at the various locations have been combined and treated as one location. The annual 24-hour maximum or daily rainfall values are published by the United States Weather Bureau. Such values are usually the maximum rain occurring between observations taken 24 hours apart. It is understood that in some cases where beginning and ending times (as shown on reports submitted by observers) indicated that all the rain fell within a 24-hour period, values for the 2 days were added. Since maximum 24-hour rainfall amounts are desired, a method of converting all maximum daily values to maximum 24-hour values was needed. Unfortunately, the only stations in or close to the area with long periods of record from which such data could be obtained are Miami, Tampa, and Jacksonville. Frequency curves for those stations were prepared, using both maximum-daily and 24-hour values and the curves for Tampa are shown on figure 1. The maximum 24-hour curve averaged about 8 percent higher than the daily curve at Miami, 13 percent higher at Tampa, and 12 percent higher at Jacksonville. This factor will be studied further, but in the meantime frequency curves based on available daily rainfall observations will be increased 10 percent and used as maximum 24-hour values.

After tabulating observed annual maximum rainfall values, the logarithms of observed values were obtained, and the mean and standard deviation of the logarithms were computed for each station as shown in table 2. Standard deviations were computed from the equation

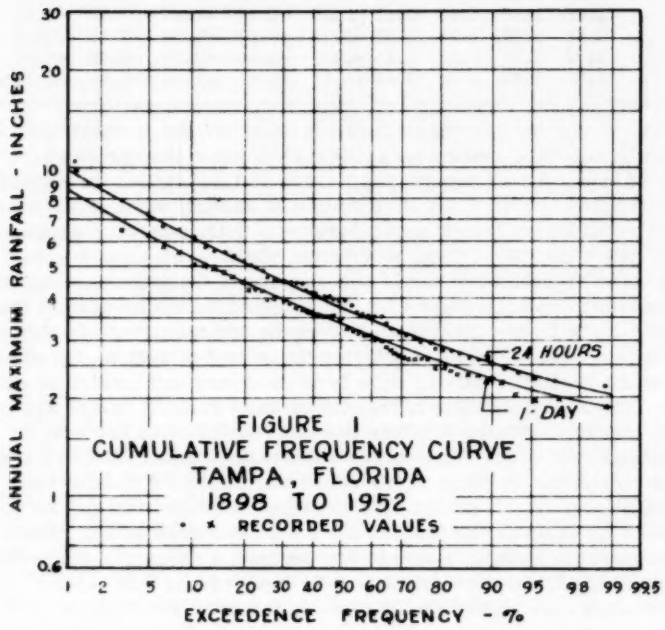


FIGURE 1
CUMULATIVE FREQUENCY CURVE
TAMPA, FLORIDA
1898 TO 1952
• × RECORDED VALUES

(1) $$\bar{s} = \sqrt{\frac{(x)^2}{n-1}}$$

in which $\bar{s}$ = standard deviation

x = deviation of a given logarithm from the mean of the logarithms

n = number of years of record

Skew coefficents were developed for a few stations with long records, using equations given by Fisher in "Statistical Methods for Research Works":

(2) $$g_1 \quad \frac{K_3}{s^3}$$

in which g_1 = The skew coefficient

$$K_3 = \frac{n}{(n-1)(n-2)} \; S_3$$

S_3 = sum of the cubes of the deviations from the mean

The observed rainfall values for each station were arranged in order of descending magnitude and plotted on log-probability paper. Plotting positions were taken from a table prepared by Beard which varies slightly from the formula

$$p = \frac{2m-1}{2n}$$

in which m = number assigned the event

Skew coefficients for the maximum daily rainfall data, when computed by formula 2, varied from +0.32 to +1.00 for a number of stations with long records. One possible explanation for the skew in the curves is the occurrence of tropical storms every few years. A preliminary analysis of tropical storms indicated it would be desirable to divide the rainfall values into two groups and prepare frequency curves for tropical and non-tropical storms independently. Unfortunately, sufficient data on tropical storms are not available for independent preparation of reliable frequency curves. After studying the distribution of observations plotted on log-probability paper and skew coefficients for key stations, it was decided to use a skew coefficient of 0.6 in developing the maximum daily frequency curve for all stations. Skew curve coordinates for a Pearson's Type III curve with a skew coefficient of 0.6 were taken from table 1. Those coefficients were used with the standard deviation and the mean of the logarithms to compute the frequency curve for each station. A typical computation of mean, standard deviation, skew, plotting position and frequency curve for part of the period of record at Hypoluxo is shown on table 2.

The difference between a frequency curve with 0.6 skew and a curve

TABLE 2

Frequency analysis for Hypoluxo, Fla.
56 years of record

Year	Max. 1-day rain		Dev. from mean	x^2	x^3	Plotting position	Rain (inches)
	Inches	Log 10	x				
1952	4.43	.6464	-.0208	.0004	.0000	1.2	13.2
1951	2.95	.4698	-.1974	.0389	-.0077	3.0	10.4
1950	4.40	.6435	-.0237	.0006	.0000	4.8	9.71
1949	3.93	.5944	-.0728	.0053	-.0003	6.6	9.70
1948	6.65	.8228	+.1556	.0242	+.0038	8.3	8.55
1947	8.55	.9320	+.2648	.0702	+.0186	10.1	8.45
1892	5.00	.6990	+.0318	.0010	.0000	98.8	2.21
Sum		37.3633		1.9017	+.1112		
Mean	4.65	.6672					

$$\overline{S} = \frac{1.9017}{56-1} = 0.1860$$

$$K_3 = \frac{56\ (.1112)}{55\ (54)} = .0021$$

$$g_1 = \frac{.0021}{(.1860)^3} = 0.326$$

Return period	2-yr.	5-yr.	10-yr.	20-yr.	50-yr.	100-yr.
Exceedence percentages	50	20	10	5	2	1
Coordinates (table 1)	-0.09	0.82	1.33	1.79	2.33	2.77
$\overline{S}$ multiplied by coordinates	-.0167	.1525	.2474	.3330	.4334	.5153
Mean log	.6672	.6672	.6672	.6672	.6672	.6672
Computed rain (log)	.6505	.8197	.9146	1.0002	1.1006	1.1825
Computed rain (inches)	4.47	6.60	8.22	10.00	12.61	15.22

which plots as a straight line on log-probability paper is shown on figure 2 for Hypoluxo. A skew coefficient of about 0.3 should be the curve of best fit for Hypoluxo but the coefficient of 0.6 adopted for the area was used.

A goodness-of-fit test was then run by determining the number of observations exceeding the values taken from the computed skew curves and comparing that number with the number that could be theoretically expected. The results of the test for 34 stations in or near the area with 1,711 years of record are given in table 3.

Although observations at some stations show varying amounts of skew, the goodness-of-fit test indicates that the curve, with a skew coefficient of 0.6, is the curve of best fit for the majority of stations in the area.

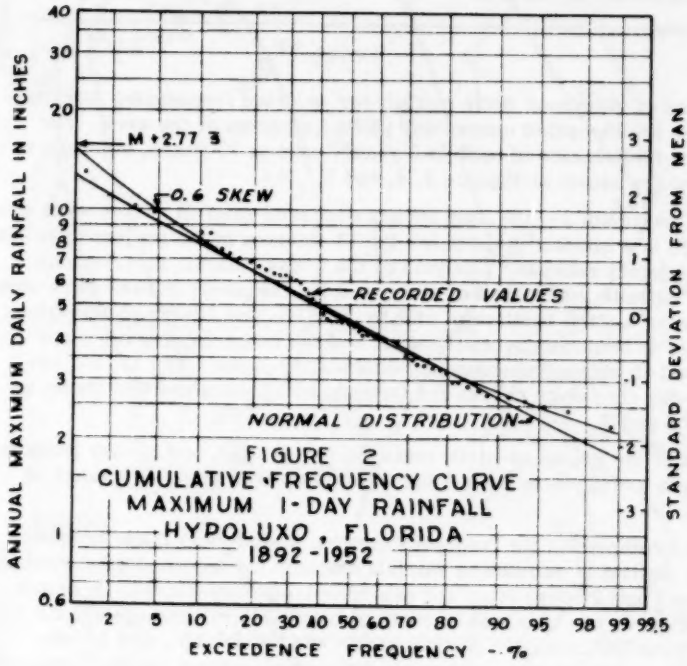


FIGURE 2
CUMULATIVE FREQUENCY CURVE
MAXIMUM 1-DAY RAINFALL
HYPOLUXO, FLORIDA
1892-1952

TABLE 3

1-day goodness-to-fit data

	Number of events exceeding computed values					
	Return period (years)					
	100	50	20	10	5	2
Observed	10	41	95	178	346	812
Theoretically expected	17	34	86	171	342	856

Values of maximum daily rainfall for selected frequencies were taken from the computed curves and plotted on maps of the area. The maps for frequencies of once in 2 years, once in 10 years, and once in 50 years are shown on figures 3, 4, and 5.

The maximum 2-, 10-, and 30-day observed rainfall values were determined in a similar manner for the 13 stations in the project area having the longest records. Analysis of the 2-day rainfall observations showed definite indications of skew, and the frequency curves were computed using a skew coefficient of 0.4. The 10- and 30-day observations appeared to be normally distributed, and the frequency curves were computed as straight lines on log-probability paper. The 1-, 2-, 10-, and 30-day frequency curves for Orlando and Homestead are shown on figures 6 and 7.

Results of the goodness-of-fit tests for the 2-, 10-, and 30-day frequency curves are given in table 4 for 13 stations with about 520 years of record.

After completing the frequency curves, a study was made to determine a method of estimating rainfall amounts for any desired duration between 1 and 30 days from the available frequency curves. A relatively smooth curve was obtained by plotting rainfall durations against the ratio between the computed daily amounts and the 2-, 10-, and 30-day amounts. As there is considerable difference between rainfall amounts along the lower east coast and in the interior, an average relationship was developed for each of those areas. The family of curves, shown on figure 8, was developed by plotting durations against rainfall ratios obtained by averaging the frequency curves at nine interior stations having long records.

CONCLUSIONS

Rainfall records for long periods are needed in order to determine variations in the shape of frequency curves at adjacent stations and to determine if independent frequency curves should be developed for tropical storms. Although large variations in the computed frequency curves do occur, a careful analysis of all available data should result in a sat-

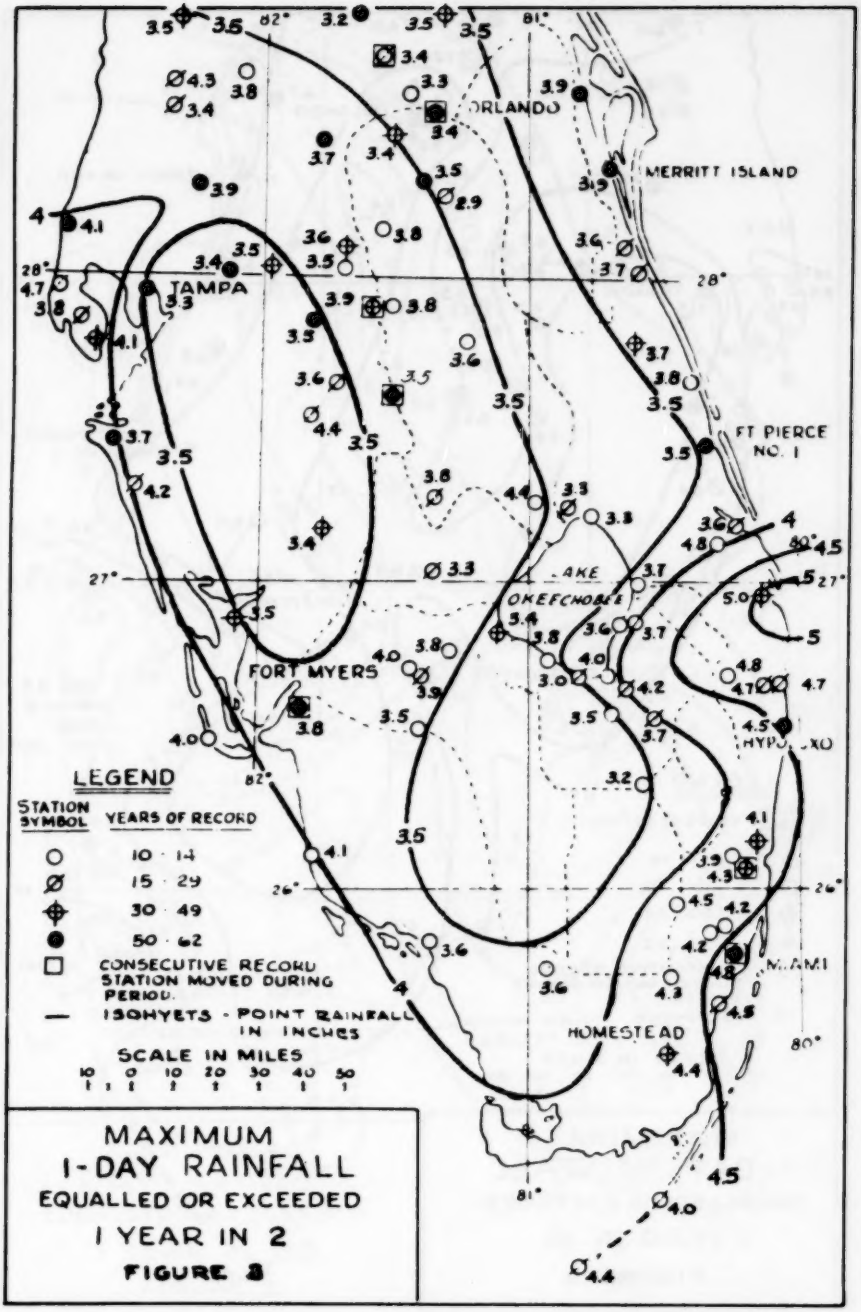
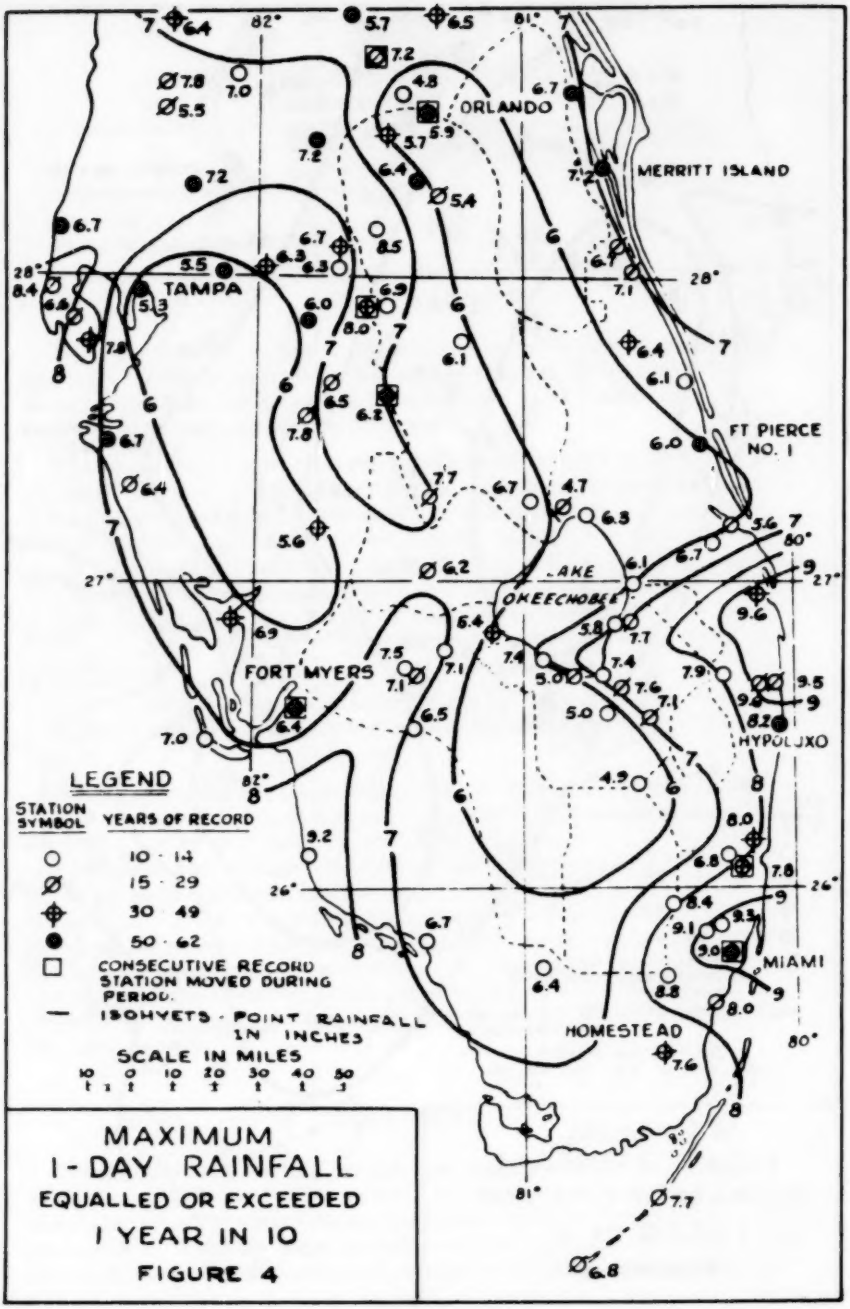
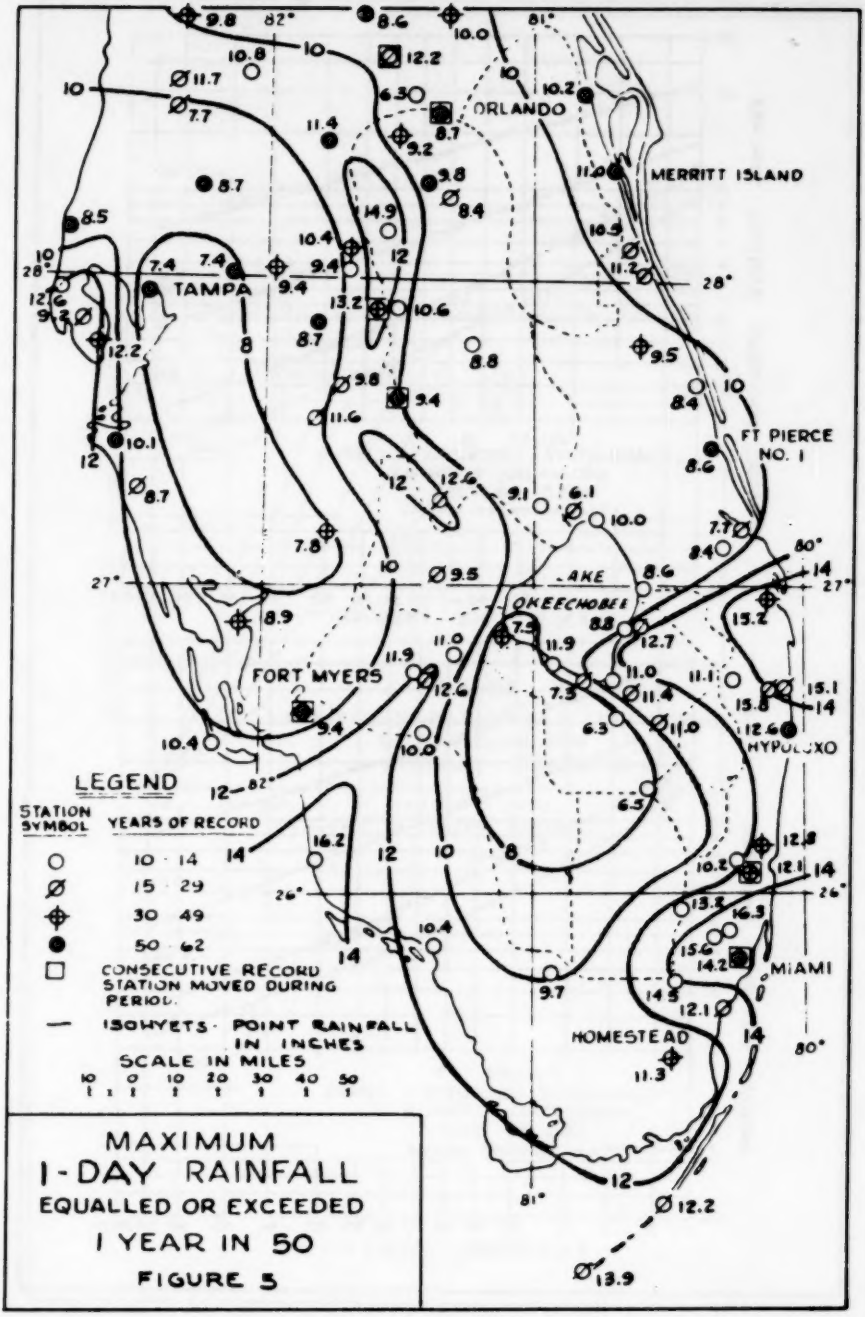

TAMPA
ORLANDO
MERRITT ISLAND
FT PIERCE NO. 1
FORT MYERS
OKEECHOBEE
HOMESTEAD
MIAMI
LEGEND
STATION SYMBOL
YEARS OF RECORD
10 - 14
15 - 29
30 - 49
50 - 62
CONSECUTIVE RECORD STATION MOVED DURING PERIOD.
ISOHYETS - POINT RAINFALL IN INCHES
SCALE IN MILES
10 0 10 20 30 40 50
MAXIMUM
1-DAY RAINFALL
EQUALLED OR EXCEEDED
1 YEAR IN 2

FIGURE 8



MAXIMUM
1-DAY RAINFALL
EQUALLED OR EXCEEDED
1 YEAR IN 10
FIGURE 4



MAXIMUM
1-DAY RAINFALL
EQUALLED OR EXCEEDED
1 YEAR IN 50
FIGURE 5

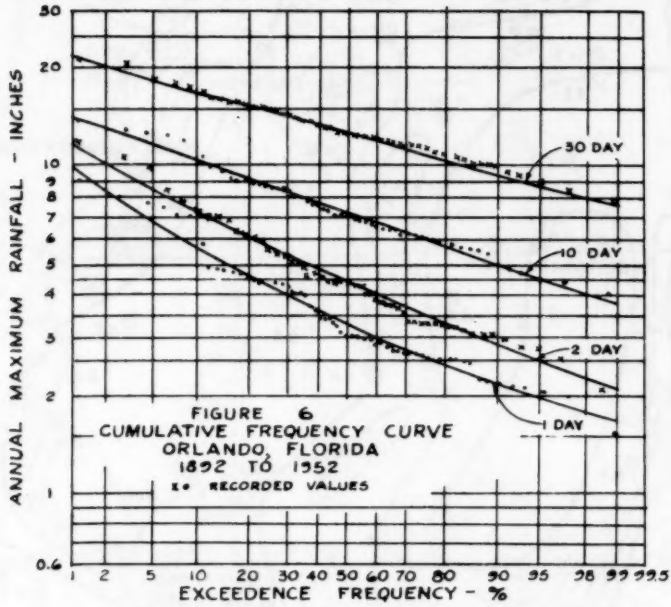


FIGURE 6
CUMULATIVE FREQUENCY CURVE
ORLANDO, FLORIDA
1892 TO 1952
x • RECORDED VALUES

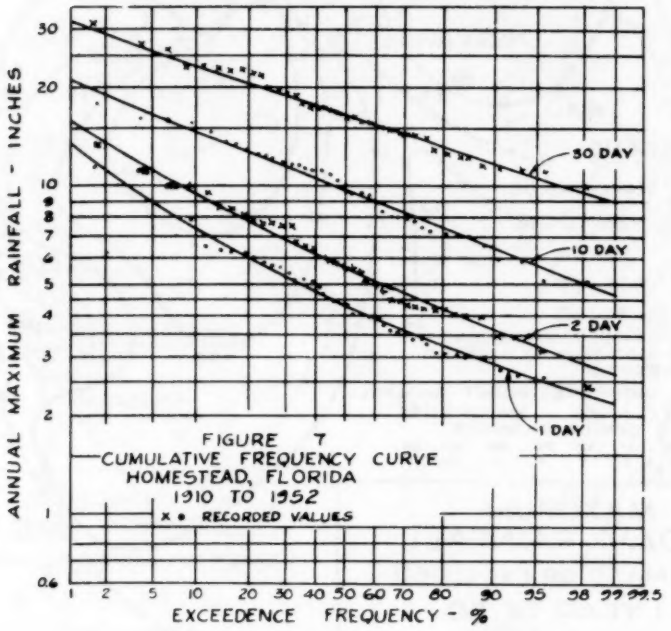


FIGURE 7
CUMULATIVE FREQUENCY CURVE
HOMESTEAD, FLORIDA
1910 TO 1952
X • RECORDED VALUES

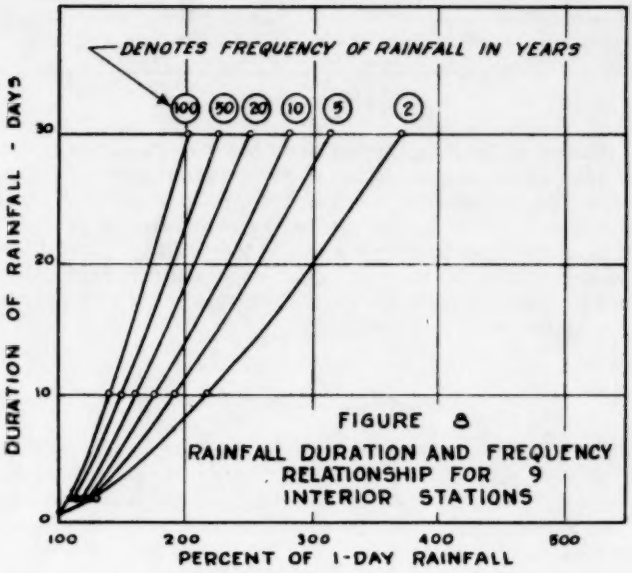


FIGURE 8
RAINFALL DURATION AND FREQUENCY RELATIONSHIP FOR 9 INTERIOR STATIONS

TABLE 4

2-, 10-, 30-day goodness-of-fit data

	Number of events exceeding computed values					
	Return period (years)					
	100	50	20	10	5	2
Observed:						
2-day	2	13	32	53	108	259
10-day	5	13	31	52	102	246
30-day	5	10	28	58	104	243
Theoretically expected	5	10	26	52	104	260

isfactory estimate of the frequency or probability of the future occurrence of rainfall of various amounts and durations. However, until more information on tropical storms has been obtained, it is not recommended that those curves be used to determine the probability of rainfall for periods much longer than 50 years, which is the estimated life of the project. Design storms for frequencies of more than 100 years should be developed by transposing large tropical storms and not taken from a frequency curve based on short records.

ACKNOWLEDGMENTS

The frequency study described was made in the Planning and Reports Branch of the Jacksonville District Office, Corps of Engineers under the supervision of H. A. Scott. Personnel assisting in the study include E. G. Brown, W. N. Moreland, R. R. Coopman, and others in the Meteorology and Regulation Section.